

22CGC053
Process Economics and Project Management

Semester 1 2022/23

In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **3 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Attempt **THREE** questions in total. Each question carries 25 marks.

Candidates should show full working for all calculations and derivations.

1. (a) (i) Briefly outline the derivation for the following expression for the net present value, NPV , arising from a set of constant annual profits P , with a cost of capital i , and project life, n .

$$NPV = P \left(\frac{1 - (1+i)^{-n}}{i} \right)$$

Eq Q1

[5 marks]

- (ii) Calculate the payback time that corresponds to a cost of capital of 10% for projects of 10 years duration. [2 marks]

- (b) A large pharmaceutical company is considering installing solar panels on the roof of its factory to reduce its electricity bill (currently 40 p per kWh). Any excess power produced by the panels that is not used by the factory will be exported (sold) to the national power grid at a rate of 24 p per kWh.

One solar panel company has provided three quotes as shown in Table Q1. Also shown in the table are estimates of how much of the power would be directed to the factory and how much would be exported to the grid. You may assume that the panels have a 10-year working life.

Table Q1: Estimated average energy supply and cost for 3 solar panel systems

Option	Daily Solar Energy Production (kWh)			Upfront cost.
	Total	Used in factory	Exported to grid	
A	100	95	5	£40 000
B	500	420	80	£150 000
C	1000	640	360	£250 000

- (i) Based on the above data and assuming a cost of capital of 10% for this type of investment, which would be the preferred option? [7 marks]
- (ii) One board member is arguing that electricity prices are likely to fall in the future. Re-evaluate the options on the assumption that electricity prices (both to and from the grid) will fall by a fraction $f = 60\%$ in year 2 and then stay constant. [7 marks]
- (iii) For the most preferred option, evaluate the fraction f that (both) electricity prices would need to fall by in year 2 (and stay constant thereafter) which would yield a zero NPV. [4 marks]

2. Unsaturated components are removed from an oil by countercurrent extraction with an immiscible solvent in a series of equilibrium mixer-settler stages with an accompanying solvent recovery unit. The quantity of oil to be processed is 800 tonnes per year.

The operating costs for the stages are £20 per tonne of total throughput (i.e. oil plus solvent). The installed capital cost of one stage is £400 per annual tonne of total throughput with a scale-up index of 0.7. If more than one stage is used then a scale-up index of 0.85 based on the number of stages can be assumed.

The solvent can be completely recovered using the solvent recovery unit. This has an operating cost of £100 per tonne of solvent, and an installed capital cost of £300 per annual tonne of solvent with a scale-up index of 0.7.

The number of stages (n) needed depends on the mass ratio of solvent to oil (S) used according to the following design equation:

$$n + 1 = \frac{\ln[1 - r(1 - KS)]}{\ln(KS)} \quad \text{Eq Q2}$$

where K is the equilibrium constant, and r is the ratio of the initial to final unsaturated concentrations.

Projects require a 15% annual net return on investment, and it is assumed that the plant depreciates over a lifetime of 10 years.

(a) Derive the following cost function for the extraction and solvent recovery.

$$CF = 10769(1 + S)^{0.7} n^{0.85} + 8077 \times S^{0.7} + 16000 + 96000 \times S \quad [9 \text{ marks}]$$

(b) Common sense suggests that S is likely to be less than 10 te/te. For an extraction where K is 0.5 and r is 100, find the approximate optimum solvent usage (to 1 decimal point) and the corresponding optimum number of stages. [14 marks]

(c) Comment on the sensitivity of the answer. [2 marks]

3. A large catalytic shell and tube, packed-bed reactor in a chemical plant requires annual maintenance and needs to be cleaned. The necessary activities are described in Table Q3-1, including the optimistic, the most likely, and the pessimistic times in hours.

Table Q3-1. Activities necessary to clean a large heat exchanger.

	Activity description	Optimistic time (hours)	Most likely time (hours)	Pessimistic time (hours)
A	Purge, flush, seal off, and disconnect reactor	1.5	1.8	2.5
B	Lift reactor clear, remove end-boxes and tube bundle	0.8	1.1	1.8
C	Clean connecting pipework	0.8	1.0	1.5
D	Clean end boxes	1.2	1.5	2.0
E	Clean shell	1.5	2.0	3.0
F	Clean inside tubes manually and by steam blast	2.0	2.25	7.0
G	Clean outside tubes	2.5	3.0	5.0
H	Inspect shell and end-boxes once they have been cleaned	0.2	0.25	0.3
I	Inspect inside tubes	0.5	0.6	0.9
J	Inspect outside tubes	0.8	0.9	1.1
K	Inspect connecting pipework once it has been cleaned	0.3	0.4	0.7
L	Reassemble, remount and reconnect reactor	2.2	2.8	4.5
M	Remove seals, flush, purge and test	1.5	1.6	2.0

Constraints on the overall job:

- (i) All job B activities should be completed before cleaning. Cleaning should be done before inspecting. Inspecting should be done before reassembly.
- (ii) The cleaning operations (jobs C to G) can run simultaneously except that the outside of the tubes must be cleaned before the inside.
- (iii) Activities I and J can be undertaken simultaneously but can only be done after both the inside and outside of the tubes have been cleaned.

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Q3 Continued/...

- (a) Draw a fully-labelled activity-on-arrow diagram for the project considering the safety of the operations. Explain with a short narrative the logic used in drawing the diagram. Label each activity with the activity code letters given and the corresponding duration. Label each node with a node number, the Earliest Event Time (EET) and the Latest Event Time (LET). [10 marks]
- (b) Determine the critical path(s) and determine if the reactor can be cleaned in 18 hours with 99% certainty. [10 marks]
- (c) Determine the probability to complete all the activities in 16 hours. [5 marks]

Data: A table of the Normal distribution is provided at the end of the paper.

4. The source temperatures, target temperatures and stream heat capacities of five process streams in a chemical plant are shown in Table Q4-1. The temperature-enthalpy diagram for this heat exchanger network is shown in Figure Q4-1.

Table Q4-1. Source temperatures, target temperatures and stream heat capacities of process streams.

Stream	Source temperature, (°C)	Target temperature (°C)	Stream heat capacity (kW/°C)
1 Hot	250	120	5.0
2 Hot	180	40	2.5
3 Hot	180	40	2.5
4 Cold	100	240	8.0
5 Cold	20	160	4.0

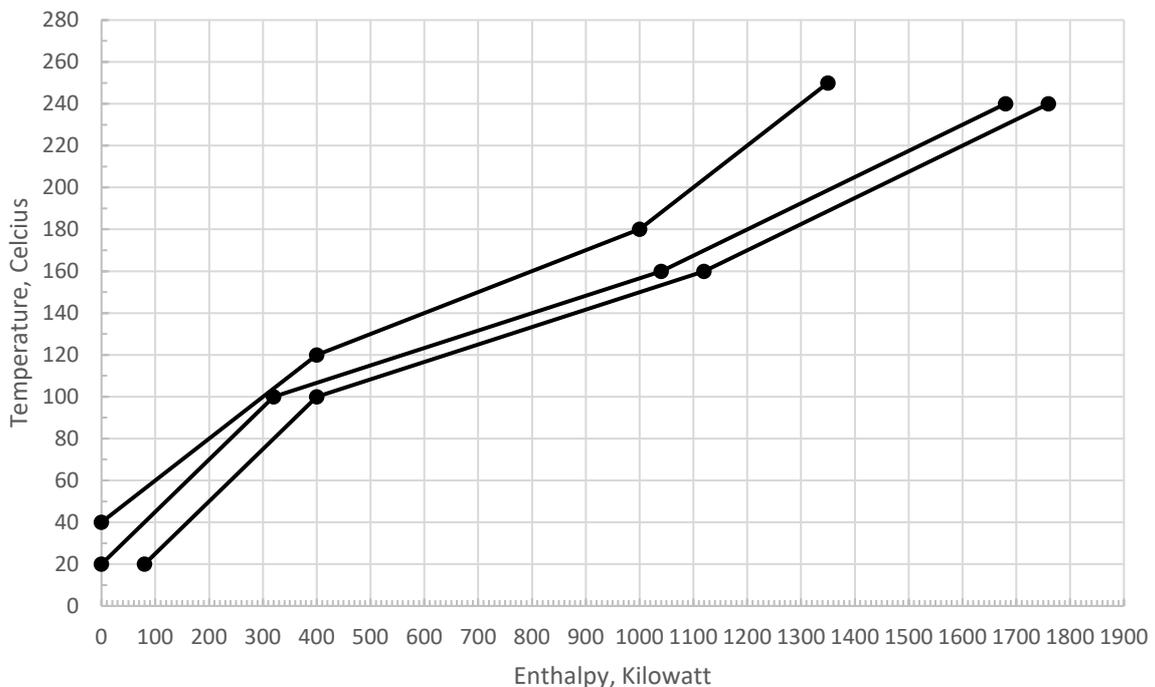


Figure Q4-1. Temperature-enthalpy diagram showing the hot line, the cold line and the cold line shifted by 80 kW. Note: Students should identify the corresponding lines by reasoning using the data provided in Table Q4-1

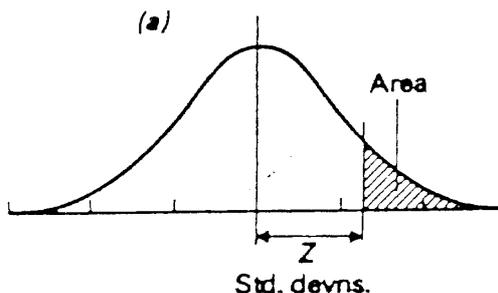
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Q4 Continued/...

- (a) Devise an efficient “common sense” design (a design that makes no reference to the Temperature-Enthalpy diagram) considering a minimum approach temperature of 20°C. [7 marks]
- (b) Fully label the “common sense” heat exchanger network, showing the temperatures of each stream across the network, the power requirement of each heat exchanger, heater or cooler and all the checks over the temperatures across the heat exchangers. [2 marks]
- (c) Draw a fully labelled heat exchanger network that maximises heat recovery and minimises utilities consumptions, considering a minimum approach temperature of 20°C. Check that the basic rules for this “pinch” design are satisfied across the network taking appropriate design actions in case the rules are not met. [12 marks]
- (d) Critically compare the “common sense” and the “pinch” design, highlighting the advantages and disadvantages of each design. [4 marks]

NORMAL DISTRIBUTION

Standard deviation from mean



↓	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.49601	.49202	.48803	.48405	.48006	.47608	.47210	.46812	.46414
0.1	.46017	.45621	.45224	.44828	.44433	.44038	.43644	.43251	.42858	.42466
0.2	.42074	.41683	.41294	.40905	.40517	.40129	.49743	.49358	.48974	.48591
0.3	.38209	.37828	.37448	.37070	.36693	.36317	.35942	.35569	.35197	.34827
0.4	.34458	.34010	.33724	.33350	.32997	.32636	.32276	.31918	.31561	.31207
0.5	.30854	.30503	.30153	.29806	.29460	.29116	.28774	.28434	.28096	.27760
0.6	.27425	.27093	.26763	.26435	.26109	.25785	.25463	.25143	.24824	.24510
0.7	.24196	.23885	.23576	.23270	.22965	.22663	.22363	.22065	.21760	.21476
0.8	.21186	.20897	.20611	.20327	.20045	.19766	.19489	.19215	.18943	.18673
0.9	.18406	.18141	.17879	.17619	.17361	.17106	.16853	.16602	.16354	.16109
1.0	.15866	.15625	.15386	.15151	.14917	.14686	.14457	.14231	.14117	.13786
1.1	.13567	.13350	.13136	.12924	.12714	.12507	.12302	.12100	.11900	.11702
1.2	.11507	.11314	.11123	.10935	.10749	.10565	.10383	.10204	.10027	.19853
1.3	.09680	.09510	.09342	.09176	.09012	.08851	.08691	.08534	.08379	.08226
1.4	.08076	.07927	.07780	.07636	.07503	.07353	.07214	.07078	.06944	.06811
1.5	.06681	.06652	.06426	.06301	.06178	.06057	.05938	.05821	.05705	.05592
1.6	.05480	.05370	.05262	.05155	.05050	.04947	.04846	.04756	.04648	.04551
1.7	.04457	.04363	.04272	.04182	.04093	.04006	.03920	.03836	.03754	.03673
1.8	.03593	.03515	.03438	.03363	.03288	.03216	.03144	.03074	.03005	.02938
1.9	.02872	.02807	.02743	.02680	.02619	.02559	.02500	.02442	.02385	.02330
2.0	.02275	.02222	.02169	.02118	.02068	.02018	.01970	.01923	.01876	.01831
2.1	.01786	.01743	.01700	.01659	.01618	.01578	.01539	.01500	.01463	.01426
2.2	.01390	.01355	.01321	.01287	.01255	.01222	.01191	.01160	.01130	.01101
2.3	.01072	.01044	.01017	.00990	.00964	.00939	.00914	.00889	.00866	.00842
2.4	.00820	.00798	.00776	.00755	.00734	.00714	.00695	.00676	.00657	.00639
2.5	.00621	.00604	.00587	.00570	.00554	.00539	.00523	.00508	.00494	.00480
2.6	.00466	.00453	.00440	.00427	.00415	.00402	.00391	.00379	.00368	.00357
2.7	.00347	.00336	.00326	.00317	.00307	.00298	.00289	.00281	.00272	.00264
2.8	.00256	.00248	.00241	.00233	.00226	.00219	.00212	.00205	.00199	.00193
2.9	.00187	.00181	.00175	.00169	.00164	.00159	.00154	.00149	.00144	.00139
3.0	.00135	.00131	.00126	.00122	.00118	.00114	.00111	.00107	.00103	.00100
3.1	.00097	.00094	.00090	.00087	.00084	.00082	.00079	.00076	.00074	.00071
3.2	.00069	.00066	.00064	.00062	.00060	.00058	.00056	.00054	.00052	.00050
3.3	.00048	.00047	.00045	.00043	.00042	.00040	.00039	.00038	.00036	.00035
3.4	.00034	.00032	.00031	.00030	.00029	.00028	.00027	.00026	.00025	.00024
3.5	.00023	.00022	.00022	.00020	.00020	.00019	.00019	.00018	.00017	.00017
3.6	.00016	.00015	.00015	.00014	.00014	.00013	.00013	.00012	.00012	.00011
3.7	.00011	.00010	.00010	.00010	.00009	.00009	.00009	.00008	.00008	.00008
3.8	.00007	.00007	.00007	.00006	.00006	.00006	.00006	.00005	.00005	.00005
3.9	.00005	.00005	.00005	.00004	.00004	.00004	.00004	.00004	.00003	.00003
4.0	.00003	.00003	.00003	.00003	.00003	.00003	.00002	.00002	.00002	.00002
4.1	.00002	.00002	.00002	.00002	.00002	.00002	.00002	.00002	.00002	.00002
4.2	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001
4.3	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001
4.4	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001

END OF PAPER

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